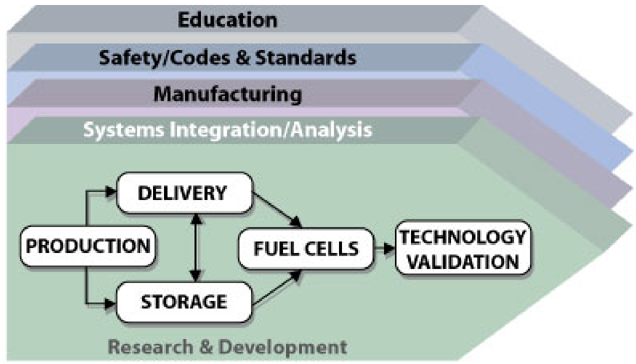
5.0 Systems Integration



The Program's Systems Integration function provides a disciplined approach to the research, design, development, and validation of complex systems ensuring that requirements are identified, verified, and met while minimizing the impact on cost and schedule of unanticipated events and interactions. Systems Integration supports the Program as it evolves and matures hydrogen production, delivery, storage, fuel cell, and supporting technologies through successive stages of research and development. The desired end point is a validated technology milestone point from which industry can develop a well-integrated hydrogen system that reliably and cost-effectively provides energy for transportation and stationary applications. The Systems Integrator provides the tools and processes to integrate and measure progress towards the goals of the Program. Tailored to the particular requirements of a robust, long-term R&D program, these tools and processes take advantage of experience and lessons learned from industry, academia, international sources, and other federal agencies (e.g., DOD and NASA).

5.1 Goal and Objectives

Goal

To support the Program in the achievement and verification of the capabilities required to reach technology readiness in 2015 effectively and at the minimum cost.

Objectives

- By 2006, establish the integrated Performance Baseline developed from the comprehensive 2015 budget estimation process. Complete external independent review of the Performance Baseline and cost estimates every third year thereafter.
- Provide value-added analyses, with resultant recommendations, which aid the R&D focus and portfolio decision-making processes of the Program.
- In cooperation with Systems Analysis: By 2008, develop and utilize a macro-system model of the hydrogen fuel infrastructure to support transportation systems. By 2010, enhance the model to include the stationary electrical generation and infrastructure as well as stochastic analysis support capabilities.
- Provide periodic independent verification of progress toward key technical targets, project performance, and ensure that the overall course of R&D satisfies Program requirements.
- Improve Program effectiveness and efficiency by the appropriate implementation of systems engineering and management processes, including risk management, value engineering, and configuration management/change control.

5.2 Approach

Systems Integration provides technical and programmatic support to the Program by 1) establishing, validating, and maintaining the Integrated Baseline as hydrogen technologies and systems are advanced from concept to technology readiness, 2) providing consistent and independent (when required) results of analyses to support programmatic decisions, 3) developing and implementing a macro-system model that addresses the overarching hydrogen fuel infrastructure as a "system," 4) verifying that technology progress and results meet Program requirements, 5) implementing formal systems engineering and value management processes that provide the Program Manager and Chief Engineer with ample insight into, and control of, the entire Program, and 6) supporting the implementation of strong program engineering and management processes. See Figure 5.2.1 for a graphic description of how the baseline, analysis, and verification functions inter-relate, along with their supporting process and management disciplines.

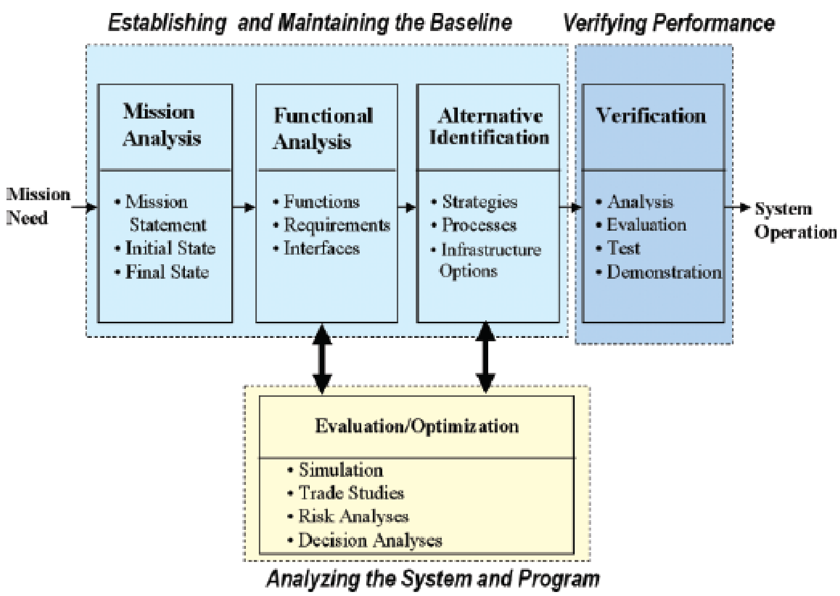


Figure 5.2.1. Systems Integration Approach Overview

Integrated Baseline

The Integrated Baseline (IB) is a tool and process that helps manage the Program by ensuring that (1) RD&D and analysis projects are properly addressing all of the Program requirements and (2) that the cost, schedule, and performance of the Program and its projects are understood and controlled. In other words, the first ensures that the Program is "doing the right things" and the second that it is "doing things right." These two components are represented by the Technical Baseline (TB) and Programmatic Baseline (PB), respectively, which are then linked by the technical objectives of the Program to provide the "integrated" aspects of the overall baseline. As shown in Figure 5.2.2, the IB is derived from the overarching policy, strategy, and planning documents associated with the President's Hydrogen Fuel Initiative. It is a representation of the entire DOE Hydrogen Program funded under that Initiative and is developed and maintained in tools that are readily available, accessible, and mature

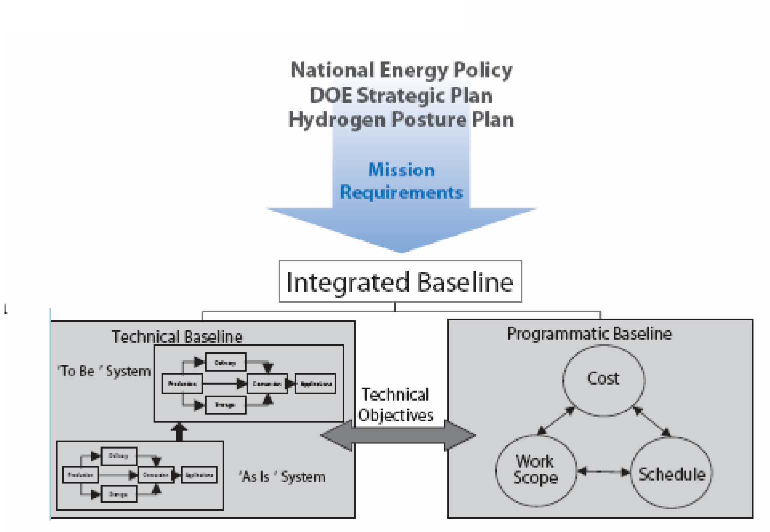


Figure 5.2.2 The Integrated Baseline

Once the IB is approved, it becomes the control version against which the Program is assessed. The Systems Integrator supports the Program in implementing a formal process to manage and control changes to the baseline as budgets are requested and appropriated, as changes in the market or policy context are identified, and as new technical advances and information become available.

Technical Baseline. To ensure that the Program is "doing the right things," the TB provides a detailed map starting from the overall requirements, down through the objectives and barriers of the individual Program elements, and finally to the task and individual project level. Requirements for the TB are drawn from the National Energy Policy, EPACT 2005, the President's Hydrogen Fuel Initiative, the Advanced Energy Initiative, and related documents: FreedomCAR and Fuel Partnership Plan, National Hydrogen Vision and Roadmap, DOE Strategic Plan, individual DOE Office strategic plans, Hydrogen Posture Plan, DOE Hydrogen Program Management and Operations Plan, and individual DOE Office Multi-Year Research, Development & Demonstration Plans.

The TB includes the prioritization of activities, as well as information on the risk level of individual activities. Questions that can be addressed and answered using the TB include:

- Does the R&D portfolio properly address all the Program requirements?
- Are there gaps or weakness in coverage of technical areas?
- Are the high priority items receiving the proper level of programmatic attention?
- Are there sufficient approaches and projects in the higher risk areas to mitigate those risks?
- When funding or focus changes, in what areas should the Program redistribute, add, or decrease resources?

The TB is a complete reference set of technical data describing the current ("as-is") state of the Program and hydrogen infrastructure. The CORE® systems engineering tool (an example CORE graphic is shown in Figure 5.2.3) in which the TB is hosted also has the capability to represent desired ("to-be") end states, in terms of hydrogen infrastructure scenarios or expected descriptions and at different points in time over the next several decades. Using this feature, the TB can be used to identify and evaluate alternative pathways for meeting the needs/requirements or responding to new infrastructure directions. The process of reviewing and validating requirements and aligning the Program with those requirements is recurrent to accommodate advances in R&D, as well as changes that result from the evolution of markets or policies, budget changes, or programmatic focus.

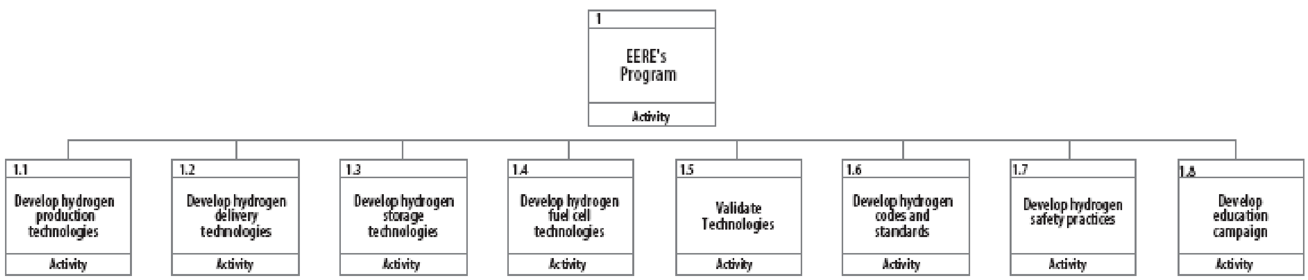


Figure 5.2.3 Example of Technical Baseline Representation from CORE

Programmatic Baseline (PB). To ensure that the Program is "doing things right," the PB provides a tool and process to track the cost, schedule, and performance of the Program at multiple work breakdown structure levels (Figure 5.2.4). The PB describes these efforts in terms of their budget, milestones, and scope, and identifies the dependencies among the activities through an integrated work breakdown structure (WBS) and master schedule. Loaded with the resources necessary to accomplish the work (funding, personnel, tools, facilities, etc.), it allows assessment of shortfalls and effects of shifting priorities or funding changes. DOE staff within each Program element use the PB to address and answer questions like the following:

- Are budgets and schedules on track – for the Program, a Program element, a task, or an individual project?
- If there is a delay in a particular activity's schedule, what is the cost and schedule impact on dependent or related activities?
- If funding is reduced in an area, what is the impact to the schedule, and if resources are reallocated, how are schedules affected?
- How does the Program scope change given different funding-level scenarios?

Once proposed changes to the PB are approved through the Change Control Board, the Systems Integrator updates and maintains the PB.

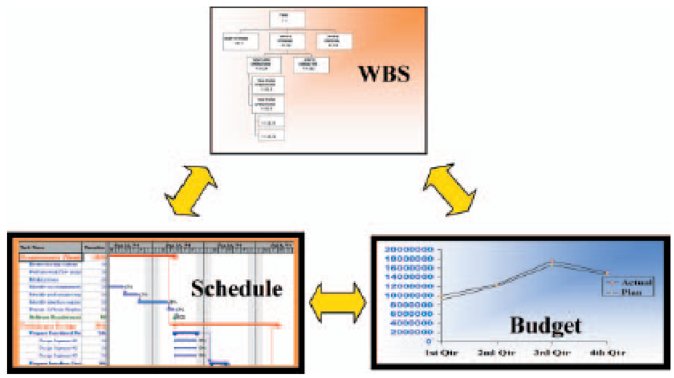


Figure 5.2.4. Programmatic Baseline Concept

Systems Analysis

Systems Integration supports the review and assessment of alternatives for satisfying the needs of a future hydrogen system and the Program's progress. This is necessary to set desired end-states for the TB and to study trade-offs between specific targets. It provides independent analysis, when required, to help ensure objective and substantiated decisions by the Program. The latter was called out as an important Program activity by the 2004 National Research Council report on "The Hydrogen Economy: Opportunities, Costs, Barriers, and R&D Needs."

Additionally, Systems Integration supports the Technology Analyst in a variety of efforts related to the overall Systems Analysis program element. These efforts include:

- Analysis of, and revisions to, the Systems Analysis Work Breakdown Structure (WBS) -- the WBS provides the plan and funding estimates for all analysis and modeling activities through 2015.
- Updates to the annual Analysis Portfolio -- this Appendix to the Systems Analysis Plan provides information on all the analysis and modeling projects funded in the current Fiscal Year.
- Conduct of Systems Analysis Conferences and Systems Analysis Working Groups -- these are important activities in terms of dissemination of Systems Analysis products, as well as analysis community input to, and review of, the Systems Analysis program element.
- Population of the Analysis Repository -- this online database captures products and outputs of all the analysis and modeling projects funded by Systems Analysis, as well as other program elements and offices contributing to hydrogen and fuel cells.

Systems Modeling

The macro-system model (MSM) will be a structure that links other existing and emerging models to support cross-cutting analysis of R&D and engineering issues. A number of models exist to analyze components and subsystems of a hydrogen infrastructure; however, the MSM will integrate many of those component and subsystem models using a common architecture and computing overall results (i.e., it is the tool that will address the overarching hydrogen fuel infrastructure as a system, including all aspects of hydrogen production/use).

The primary objective of the MSM will be to support programmatic decisions regarding investment levels and to focus R&D. The MSM will be utilized to address overarching analysis questions. Examples of these questions include system option-analysis regarding hydrogen quality, feedback effects of infrastructure development on production cost, and changes in emissions due to a growing hydrogen infrastructure. The MSM will be a tool that estimates how and when proposed technologies might fit into a national energy infrastructure.

The MSM is being developed on the Enterprise Modeling Framework (EMF) that is an outgrowth of High Level Architecture (HLA). HLA is a general-purpose architecture for simulation reuse and interoperability that was developed by the Defense Modeling and Simulation Office (DMSO) to run large, distributed war games. HLA links component models to analyze cross-cutting issues; in this case, well-to-wheels pathway analysis, hydrogen quality, and other issues. We selected HLA because, like the DMSO problem, the MSM requires interaction of many component models and has both spatial and temporal issues.

Technical Performance Verification

As the Program develops new technologies and produces research results, Systems Integration facilitates technical reviews at key stages to evaluate strategic fit with Program objectives, technical potential, economic/market potential, and environmental, health, and safety considerations along with the plan for further development. Verification will be accomplished through analysis, testing, and/or demonstration. Criteria and approaches will vary depending on the maturity of the technology. For example, at early stages of development, information available to evaluate concepts is likely to be more general and have higher uncertainty than that available at later stages. Information stemming from these reviews will be used to re-evaluate the baseline.

In some cases, Systems Integration convenes technical review panels of peer experts to provide an independent assessment and recommendation to DOE for consideration during the decision process. This is particularly true for major Go/No-Go decisions of the Program, as well as when an assessment of progress toward one of the key technical targets of the Program is warranted. In FY2006, for example, independent analyses are being conducted to support Go/No-Go decisions pertaining to cryo-compressed hydrogen storage and single-walled carbon nanotubes for hydrogen storage. Moreover, independent analyses were conducted on progress towards achieving key technical targets for fuel cell system costs and production cost of hydrogen from distributed steam methane reforming.

The Systems Integrator works closely with the DOE Technology Development Managers to bring knowledge of system-level requirements and review criteria to planning and execution. In particular, the Systems Integrator supports reviews of the following Program activities:

- Peer review for all projects and activities
- Independent review panels for key Program milestones and Go/No-Go decisions
- Stage Gate reviews at key progress points for significant projects.

Systems Engineering and Value Management

Systems Integration supports the Program by aiding implementation of several key processes, three of which are described below:

Risk Management. Systems Integration supports implementation of a risk management process to identify potential Program risks and determine actions that will mitigate the impact of those risks. The Risk Management Plan (RMP) describes methods for identifying, assessing, prioritizing, and analyzing risk drivers; developing risk-handling plans; and planning for adequate resources to handle risk. The RMP assigns specific responsibilities for the management of risk and prescribes the documenting, monitoring, and reporting processes to be followed. A six-step risk process—risk awareness, identification, quantification, handling, impact determination, and reporting and tracking—will be used. Throughout the life of the Program, the Systems Integrator helps identify "potential" risks, focusing on the critical areas that could affect the outcome of the Program such as:

- System Requirements
- Environment, Safety, and Health
- Modeling and Simulation Accuracy
- Technology Capability
- Budget and Funding Management
- Schedule
- Stakeholder, Legal, and Regulatory Issues.

Configuration Management. Systems Integration manages the evolving configuration of the Technical Baseline and continuously monitors and controls it. Changes to the Technical Baseline and the Programmatic Baseline (the approved work scope, schedule, and cost) must both be controlled to ensure that all work being performed is consistent with the approved technical requirements and the current configuration, and that potential impacts throughout the Integrated Baseline are considered before actions are taken. A formal change control process has been established to ensure that the potential impacts of proposed changes to either the Technical Baseline or the Programmatic Baseline are evaluated, coordinated, controlled, reviewed, approved, and documented in a manner that best serves the Program and its projects. The decision-making body within the Program for approving proposed changes is the Change Control Board, headed by the Chief Engineer. The procedures and processes will be documented in a Configuration Management Plan.

Earned Value Management System. The Program is comprised of numerous complex projects, many of which are on the leading edge of technology. To be successful, the Program Manager must have ample insight to, and control of, the entire Program. An element of that insight and control is provided by implementing an Earned Value Management System (EVMS) in accordance with direction from the Secretary of Energy and DOE Order 413.3, *Program and Project Management for the Acquisition of Capital Assets*. The EVMS for the Program follows the guidance provided in the Department's (Draft) *Earned Value Management Application Guide* (Version 1.6, January 1, 2005.)

This guidance includes tailoring the EVMS for a research and development program, such as the DOE Hydrogen Program.

By implementing a tailored, top-level EVMS process, the Program management team is able to:

- Establish a standard approach for organizing the various elements of the Program
- Facilitate the formation of a comprehensive time-phased budget based on thorough schedule planning and cost estimating
- Capture actual costs incurred by the Program
- Determine real, specific work progress on the Program in terms of cost and schedule
- Measure performance against an approved Program baseline.

Program Support

Systems Integration provides analyses and recommends DOE-sponsored activities to make sure R&D results are shared throughout the hydrogen community, thus ensuring the development of the necessary technological capabilities at the lowest possible cost. Specific support is provided to the overall Program in the following areas:

- Annual Merit Review -- Systems Integration coordinates the conduct of the annual review of the Program, during which typically 250 funded projects present their results in oral or poster formats. In addition, a team of ~150 peer reviewers evaluate approximately one-half of the presented projects for feedback to the Program.
- Annual Progress Report -- This annual report, in professional journal format, summarizes the objectives, approach, technical accomplishments, and future plans for each of the projects funded by the Program.
- Hydrogen Technical Advisory Committee (HTAC) -- Systems Integration provides coordination and technical support to this FACA-level committee which reviews the Program and provides information and recommendations to the Secretary of Energy.
- DOE Hydrogen Program Website -- This website provides a one-stop-shop for all the hydrogen and fuel cell activities of DOE, across the offices of EERE, FE, NE, and SC.

5.3 Programmatic Status

Table 5.3.1 provides the current set of Systems Integration activities.

Table 5.3.1. Current FY06 Systems Integration Activities

Activities	Description
Integrated Baseline	▪ Technical Baseline: Establish an initial version of the technical baseline, containing requirements, tasks, objectives, barriers, technical targets and projects, in CORE®. ▪ Programmatic Baseline: Conduct a Budget Estimation exercise for the entire Program, yielding a detailed WBS, schedule and budget estimates for each Program Element and enter into the CORE® baseline. ▪ Support the development of an overall Program Master Schedule
Systems Analysis	▪ Develop the Systems Analysis Plan with the Technology Analyst ▪ Support Hydrogen Analysis Resource Center (HyARC) development activities ▪ Support the Technology Analyst in technical management and monitoring of analysis projects ▪ Produce the initial version of the Analysis Repository
Systems Modeling	▪ Define requirements for the Macro-System Model (MSM) ▪ Adapt the Enterprise Modeling Framework for integrating hydrogen models ▪ Integrate an initial set of models including H2A production, the hydrogen delivery scenario model (HDSAM), GREET, HyARC ▪ Begin independent reviews/testing of the MSM
Verification of Technical Performance	▪ Conduct the Annual Merit Review meeting and issue report ▪ Support HTAC ▪ Choose and acquire resources to perform independent assessment of progress on key technical targets ▪ Example: Conduct an independent analysis of cryo-compressed storage technologies to meet technical targets (supports FY06 go/no-go decision)
Systems Engineering and Value Management	▪ Publish the Annual Progress Report ▪ Produce the Configuration Management Plan ▪ Facilitate Change Control processes and boards to update the Multi-Year Plan ▪ Produce the Risk Management Plan and initiate pathfinder risk analysis activities to support the budget process ▪ Provide timely and value-added updates to the DOE Hydrogen Program website

5.4 Challenges

The following discussion details the various technical and programmatic barriers that must be overcome to attain the DOE Hydrogen Program Systems Integration goal and objectives.

A. Program Complexity. The DOE Hydrogen Program is comprised of nearly 300 projects spread across different organizations, addressing a variety of technological disciplines, many of which are on the leading edge of technology. Further complicating the ability to properly integrate the Program is the geographical dispersal of these organizations, the long-term duration of the Program, and the multitude of external stakeholders. The breadth and depth of the Program make it a challenge to encompass all aspects into the Integrated Baseline. Both vertical and horizontal integration will be necessary to integrate the Program under a unified system and to ensure integrated management and optimization of work flow across organizational boundaries. Completeness is important, because a true assessment of the sufficiency of program efforts against the requirements can only be made if the entire Program is represented. The four DOE offices (EERE, FE, NE, and SC) and other programs and agencies (e.g. Department of Transportation) that are involved in work under the President's *Hydrogen Fuel Initiative* each have their own baselining and scheduling requirements, which must be consistent and interrelated.

B. Adopting System Integration Functions to an R&D Program. Systems integration has most often been applied to the design, development, production, and maintenance of large, complex acquisition or construction projects. Implementing systems integration within an ongoing R&D program without delaying or disrupting current efforts represents a significant challenge, especially when the process has not been institutionalized within the organization.

C. Inherent Uncertainty in R&D. Most systems integration and engineering efforts have been applied to large hardware and software acquisition projects, not R&D programs. Given the inherent uncertainties with regard to achieving desired outcomes from the research and development of new technologies, tailoring the systems integration procedures and tools to the R&D paradigm will be a challenge, as will be gaining Program and stakeholder acceptance of these processes as value-added and important to both Program Element and overall Program success.

D. Accessibility/Availability of Technical Information. The cost-effective availability and accessibility of the most up-to-date technical results are necessary to support programmatic decision making. Within the Program, technical information relevant to a particular issue must be collected from a wide array of sources—from people in different organizations, who developed it originally without necessarily considering its role in management decision-making. To ensure that results from many sources are technically and practically realistic, these diverse technical results require a vetting process.

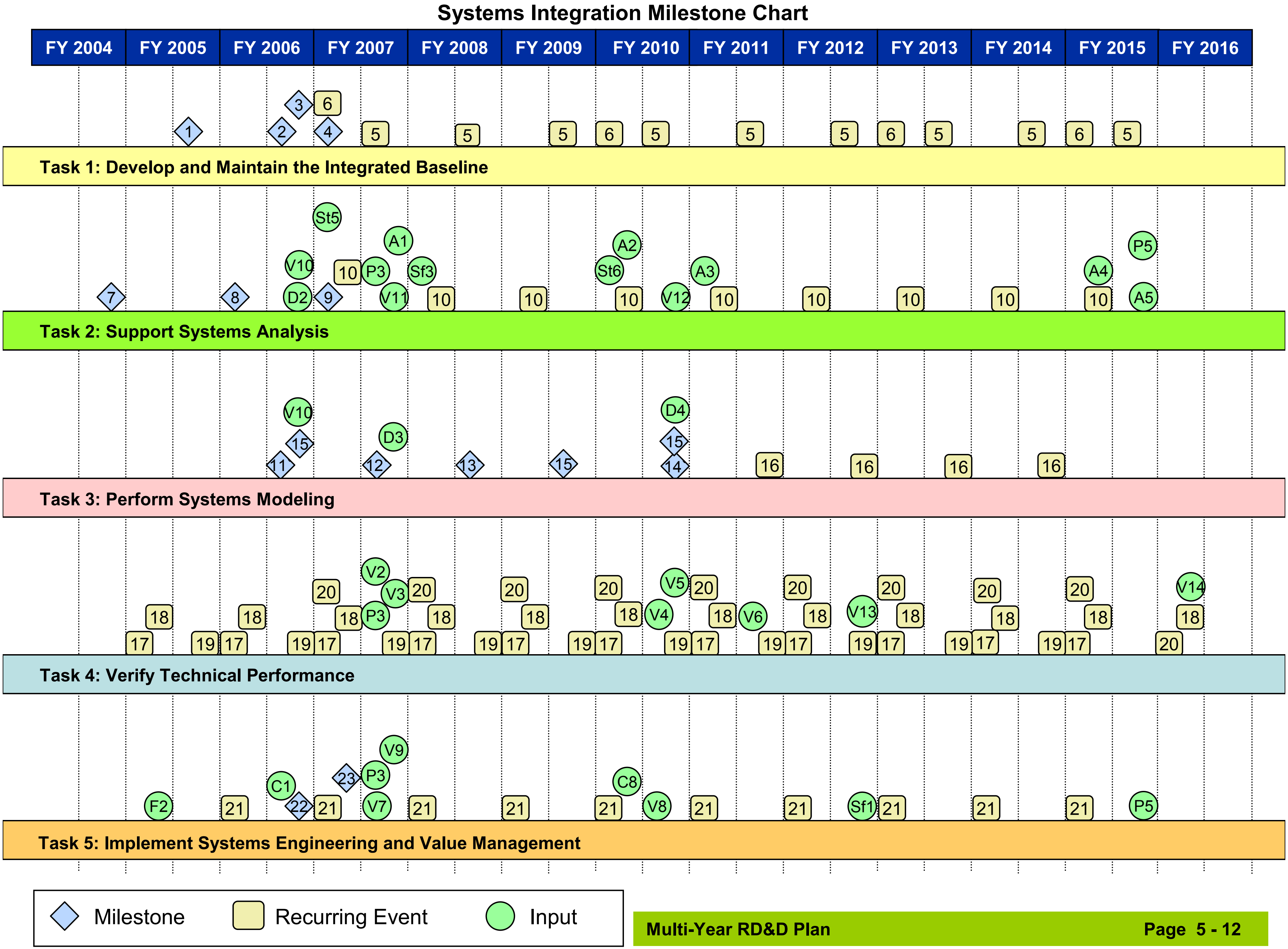
5.5 Task Descriptions

The task descriptions are presented in Table 5.5.1.

Table 5.5.1. Tasks		
Task	**Description**	**Challenges**
1	**Develop and Maintain the Integrated Baseline (IB)** ▪ Support updates to the Program master budget and schedule ▪ Plan for the independent review of cost estimates ▪ Update IB quarterly ▪ Prepare for Independent Review of IB ▪ Provide on-line access to IB ▪ Update the Program Requirements Document	A, B, C
2	**Support Systems Analysis** ▪ Update the Analysis Portfolio ▪ Support Systems Analysis WBS updates ▪ Provide support to the Cross-Cut Team ▪ Facilitate the first Systems Analysis Conference ▪ Facilitate two Systems Analysis Working Group meetings ▪ Complete population of the Analysis Repository and provide online ▪ Update the Systems Analysis website areas	C, D
3	**Perform System Modeling** ▪ Develop and maintain the MSM infrastructure ▪ Integrate Production / Delivery Models ▪ Commence Integration of vehicle cost/performance models ▪ Link one transition model to the MSM ▪ Analyze hydrogen quality issues, as test for the MSM ▪ Organize MSM Working and Steering Teams ▪ Provide other system modeling support to the Technology Analyst	A, D
4	**Verify Technical Performance** ▪ Conduct Go/No-Go Reviews ▪ Perform Stage Gate Reviews ▪ Conduct independent Technical Target Assessments ▪ Conduct Annual Merit Review and issue report ▪ Support HTAC technical needs and reporting	A, B, C
5	**Implement Systems Engineering and Value Management** ▪ Prepare and implement Systems Engineering Management Plan ▪ Prepare the Annual Progress Report ▪ Continue Change Management/Change Control processes ▪ Implement Risk Management support to the Program and Technology Analyst ▪ Finalize the Quality Manual ▪ Update DOE Hydrogen Program website ▪ Develop and Implement Value Management Program including a Systems Integration Website ▪ Perform Planning and Reporting	A, B

5.6 Milestones

The following chart shows the interrelationship of milestones, tasks, and supporting inputs from other Program elements for the Systems Integration function through FY2016. The inputs/outputs are also summarized in Appendix B.



Systems Integration Milestone Chart
FY 2004
FY 2005
FY 2006
FY 2007
FY 2008
FY 2009
FY 2010
FY 2011
FY 2012
FY 2013
FY 2014
FY 2015
FY 2016
Task 1: Develop and Maintain the Integrated Baseline
Task 2: Support Systems Analysis
Task 3: Perform Systems Modeling
Task 4: Verify Technical Performance
Task 5: Implement Systems Engineering and Value Management
Milestone
Recurring Event
Input

Task 1: Develop and Maintain the Integrated Baseline	
1	Initial Integrated Baseline completed. (3Q, 2005)
2	Budget Estimate and Master Schedule through 2015 complete. (3Q, 2006)
3	Requirement Document delivered. (4Q, 2006)
4	Integrated Programmatic and Technical Baselines complete. (1Q, 2007)
5	Updates to Integrated Baseline (usually quarterly, or as required). (3Q, 2007; 3Q, 2008; 3Q, 2009; 3Q, 2010; 3Q, 2011; 3Q, 2012; 3Q, 2013; 3Q, 2014; 3Q, 2015)
6	Independent reviews of Baseline and Program cost estimates. (1Q, 2007; 1Q, 2010; 1Q, 2013; 1Q, 2015)

Task 2: Support Systems Analysis	
7	Independent technical analysis of on-board fuel processing go/no-go. (4Q, 2004)
8	Systems Analysis Plan/Analysis Portfolio development support complete. (1Q, 2006)
9	Analysis Repository complete and online. (1Q, 2007)
10	Analysis Portfolio and Analysis Repository annual updates. (2Q, 2007; 2Q, 2008; 2Q, 2009; 2Q, 2010; 2Q, 2011; 2Q, 2012; 2Q, 2013; 2Q, 2014; 2Q, 2015)

Task 3: Perform Systems Modeling	
11	Complete Version 1 of the Macro-System Model (Production, Delivery, GREET). (3Q, 2006)
12	Complete Version IIA of the MSM (one Transition Model). (3Q, 2007)
13	Complete Version IIB of the MSM (multiple Transition Models). (3Q, 2008)
14	Complete Version III of the MSM (stochastic capabilities). (4Q, 2010)
15	MSM analysis test cases. (4Q, 2006; 3Q, 2009; 4Q, 2010)
16	MSM updates. (4Q, 2011; 4Q, 2012; 4Q, 2013; 4Q, 2014)

Task 4: Verify Technical Performance	
17	Annual Merit Review Peer Review Report published. (1Q, 2005; 1Q, 2006; 1Q, 2007; 1Q, 2008; 1Q, 2009; 1Q, 2010; 1Q, 2011; 1Q, 2012; 1Q, 2013; 1Q, 2014; 1Q, 2015)
18	Produce Annual Progress Report. (2Q, 2005; 2Q, 2006; 2Q, 2007; 2Q, 2008; 2Q, 2009; 2Q, 2010; 2Q, 2011; 2Q, 2012; 2Q, 2013; 2Q, 2014; 2Q, 2015; 2Q, 2016)
19	Independent Reviews of progress on Technical Targets. (4Q, 2005; 4Q, 2006; 4Q, 2007; 4Q, 2008; 4Q, 2009; 4Q, 2010; 4Q, 2011; 4Q, 2012; 4Q, 2013; 4Q, 2014)
20	Facilitate HTAC meetings and provide technical support. (1Q, 2007; 1Q, 2008; 1Q, 2009; 1Q, 2010; 1Q, 2011; 1Q, 2012; 1Q, 2013; 1Q, 2014; 1Q, 2015; 1Q, 2016)

Task 5: Implement Systems Engineering and Value Management	
21	Update MY RD&D Plan as needed. (1Q, 2006; 1Q, 2007; 1Q, 2008; 1Q, 2009; 1Q, 2010; 1Q, 2011; 1Q, 2012; 1Q, 2013; 1Q, 2014; 1Q, 2015)
22	Final Risk Management Plan complete. (4Q, 2006)
23	Final Configuration Management Plan complete. (2Q, 2007)

Inputs

P3 Impact of hydrogen quality on cost and performance. (3Q, 2007)

P5 Hydrogen production technology for distributed systems. (4Q, 2015)

D2 Hydrogen containment composition and issues. (4Q, 2006)

D3 Hydrogen delivery infrastructure analysis results. (4Q, 2007)

D4 Assessment of impact of hydrogen quality requirements on cost and performance of hydrogen delivery. (4Q, 2010)

St5 Baseline hydrogen on-board storage system analysis results including hydrogen quality needs and interface issues. (1Q, 2007)

St6 Final On-board Hydrogen storage system analysis results of cost and performance; and down-select to a primary on-board storage system candidate. (1Q, 2010)

F2 Develop preliminary Hydrogen quality requirements. (2Q, 2005)

V2 Final report for first generation vehicles, interim progress report for second generation vehicles, on performance, safety, and O&M. (3Q, 2007)

V3 Technology Status Report and re-focused R&D recommendations. (4Q, 2007)

V4 Final report for second generation vehicles on performance, safety, and O&M. (3Q, 2010)

V5 Technology Status Report and re-focused R&D recommendations. (4Q, 2010)

V6 Validate Cold Start-Up capability (in a vehicle with an 8-hour soak) meeting 2005 requirements (specify cold-start energy). (3Q, 2011)

V7 Final report on infrastructure and hydrogen quality for first generation vehicles. (3Q, 2007)

V8 Final report on infrastructure, including impact of hydrogen quality for second generation vehicles. (3Q, 2010)

V9 Final report on safety and O&M of three refueling stations. (4Q, 2007)

V10 Hydrogen refueling station analysis – proposed interstate refueling station locations. (4Q, 2006)

V11 Composite results of analyses and modeling from vehicle and infrastructure data collected under the Learning Demonstration Project. (4Q, 2007)

V12 Final composite results of analyses and modeling from vehicle and infrastructure data collected under the Learning Demonstration Project. (4Q, 2010)

V13 Report on 3500 hour durability test. (4Q, 2012)

V14 Report on the status of the Validation of the 5000 hour durability and cold start capability. (2Q, 2016)

C1 Completed hydrogen fuel quality standard as ISO Technical Specification. (3Q, 2006)

C8 Final Hydrogen Fuel quality standard as ISO standard. (2Q, 2010)

Sf1 Sensors meeting technical targets. (4Q, 2012)

Sf3 Final peer reviewed Best Practices Handbook. (1Q, 2008)

A1 Complete techno-economic analysis on production technologies currently being researched to meet overall Program hydrogen fuel objective. (4Q, 2007)

A2 Issue a report on the infrastructure analysis for the hydrogen scenarios. (2Q, 2010)

A3 Issue a report on the status of the technologies and infrastructure to meet the demands for the hydrogen fuel and vehicles. (1Q, 2011)

A4 Issue a report on the results of the infrastructure analysis for the long term technologies and requirements for technology readiness. (2Q, 2015)

A5 Issue report of the environmental analysis of the Hydrogen Program. (4Q, 2015)

Outputs

Note: None for Systems Integration. Per agreement in FY05, System Integration outputs/products are for the entire Program, not individual Program Elements, so did not make sense to make every Program Element show them as Inputs.